IN THE SPECIFICATION:

Please amend paragraph **[0001]** as follows:

[0001] This application is a continuation of application Serial No. 10/016,479, filed December 7, 2001, ~~pending.~~ now U.S. Patent 6,776,049, issued August 17, 2004.

Please amend paragraph **[0002]** as follows:

[0002] Field of the Invention: The present invention relates to instrumented sensors and to apparatus and methods for measuring or predicting stress and/or stress component(s) at an interface, such as a bond line, a joint, ~~etc.~~ etc., of mated bodies.

Please amend paragraph **[0015]** as follows:

[0015] The sensor body preferably comprises third and fourth walls spaced apart from and opposing one another and each extending in a respective plane parallel to the y-axis, the third and fourth walls coupling the first and second walls to one another to provide a block with a quadrangular ~~cross section~~ cross-section (when in a nondeformed state). In one embodiment, the quadrangular ~~cross section~~ cross-section is rectangular. In another embodiment, the quadrangular ~~cross section~~ cross-section is rectangular and has a length-to-height ratio of about 4 to 1. In still another embodiment, the quadrangular ~~cross section~~ cross-section is square. The sensor body may have an open chamber with a periphery bounded by the first, second, third, and fourth walls.

Please amend paragraph **[0025]** as follows:

[0025] Preferably, but optionally, the method comprises using a plurality of the stress sensors. Also ~~preferably~~ preferably, but optionally, the data-receiving device comprises at least one of a data processor and a data display.

Please amend paragraph **[0026]** as follows:

[0026] The method of this aspect of the invention is useful for measuring stresses imparted by physical loads in a rocket motor, such as during launch of the rocket motor. For example, the first body may comprise a casing member or, more likely, an insulation layer of a rocket ~~motor~~ motor, and the second body may comprise a solid propellant grain of the rocket motor. In this method, it is especially desirable to embed the sensor in the liner situated between the solid propellant grain and the insulated casing member.

Please amend paragraph **[0043]** as follows:

[0043] The shear stress ~~data, and~~ data and, in some ~~instances~~ instances, other data ~~as well,~~ from the stress sensor or stress sensors 10 can be used to simulate, estimate or otherwise predict the same stresses that are occurring at the interface of the insulation layer 88/casing member 82 and the solid propellant 84. Fully understanding shear stresses at this interface permits satisfactory adhesive liners 86 to be selected with high confidence.

Please amend paragraph **[0044]** as follows:

[0044] FIG. 2 shows a functional block diagram of a system 50 in accordance with a presently preferred system embodiment of the invention, which would be suitable, for example, for predicting stresses in the stress sensors 10. The system 50 comprises at least one instrumented stress sensor 10 according to a presently preferred embodiment, in which the stress sensor 10 comprises a reflective sensing device. Each stress sensor 10 may be assumed, for purposes of reference and illustration, to be situated parallel to a longitudinal axis of the insulated casing member 82. Stress sensors 10, for example, may ~~be, for example,~~ be distributed uniformly about the circumference of the annular interface of the insulation layer 88 and the solid propellant 84.

Please amend paragraph **[0045]** as follows:

[0045] The system 50 also comprises a data-receiving device comprising a processor 54,~~e.g.,~~ such as the processor of a commercially available personal computer or small business computer, a display monitor 59, and a storage device 58, e.g., a hard drive on a computer. A data recording device ~~60~~ 60, such as a strip chart recorder or other device useful for recording data from the stress sensors ~~10~~ 10, may be electronically connected to the processor 54. A signal conditioner (also referred to herein as a sensor measurement output device) 56 is coupled between the stress sensors 10 and the processor 54 for communicating the sensor measurement output signals to the ~~environment — e.g.,~~ environment, e.g., the data-receiving ~~device — outside~~ device, outside of the instrumented sensor 10.

Please amend paragraph **[0046]** as follows:

[0046] An instrumented stress sensor 10 according to a first presently preferred embodiment of this aspect of the invention is shown in side cut-away view in FIG. 3. The sensor 10 comprises a sensor body (or sensor housing) 12 including a first wall 14 and a second wall 16 coupled to one another. The first wall 14 and second wall 16 each ~~having~~ have a respective portion opposing one another. The opposing portions of the first wall 14 and second wall 16 extend parallel to the interface of the insulation layer 88 and the solid propellant 84. Conventional adhesives, such as an epoxy, may be used for coupling the outer surface of the first wall 14 to the solid propellant and for coupling the outer surface of the second wall 16 to the insulation layer 88. To aid in illustration, a conventional three-axis Cartesian coordinate system may be assumed to exist at the sensor body 12. The x-axis of the Cartesian coordinate system is assumed to extend parallel to and equidistant from the opposing portions of the first and second walls 14 and 16. Mutually orthogonal ~~y and z axes~~ y- and z-axes are assumed to lie in a plane normal to the ~~x axis,~~ x-axis, with the ~~y axis~~ y-axis extending between the opposing portions of the first wall 14 and the second wall 16. (Although not shown, the z-axis extends out of the sheet on which FIG. 3 is illustrated.) The instrumented stress sensors 10, as described hereinbelow, each use a respective sensing device 30 to measure the stress in the sensor body 12, preferably a

shear component of the stress in the sensor body 12. Optionally, the instrumented stress sensors 10 may also use the sensing device 30 to measure a normal component of the stress in the sensor body.

Please amend paragraph **[0047]** as follows:

[0047] The opposing portions of the first wall 14 and the second wall 16 as referred to herein need not constitute the entirety of the first wall 14 and the second wall 16 that is subject to shear stresses. The opposing ~~portions do, however,~~ portions, however, do comprise at least a portion of the sensor body that is subject to stress, which in many cases will include the entireties of the first wall 14 and second ~~walls 14 and~~ wall 16. The opposing portions, as the term is used herein, refer to any area or region of the first wall 14 and second ~~walls 14 and~~ wall 16 that is suitable for measurement of shear stresses under the application and circumstances. Preferably, the opposing portions are selected to be regions of the sensor body that experience substantial stress relative to other parts of the sensor body during normal operating ~~conditions, and which~~ conditions and are representative of the stress occurring in the entire portion of the interface ~~that is~~ subject to such shear forces.

Please amend paragraph **[0048]** as follows:

[0048] The illustrated sensor body 12 comprises a third wall 18 and a fourth wall 20 spaced apart from and opposing one another. The third wall 18 and fourth ~~walls 18,~~ wall 20 each extend in a respective plane parallel to the y-z plane and couple the first wall 14 and second ~~walls~~ wall 16 to one another to provide a block having a chamber 38. The ratio of the length to the height of the sensor body 12 can be chosen to achieve the desired sensitivity characteristics. As illustrated, the sensor body 12 has a quadrangular ~~cross section~~ cross-section and, more particularly, a rectangular ~~cross section~~ cross-section with a length-to-height ratio of about 4 to 1. It is to be understood that the length-to-height ratio may be 1 to 1 (for increasing shear sensitivity) to give a square ~~cross section,~~ cross-section, or the sensor body 12 may have more than four sides and/or one or more nonlinear walls. The sensor body 12 may further comprise

fifth and sixth walls extending parallel to the x-y plane and integrally coupled to the first, second, third and fourth walls to bound an enclosed chamber. Preferably, the walls of the sensor body 12 comprise aluminum and, more preferably, consist essentially of aluminum. Also preferably, the walls of the sensor body 12 all have the same thickness.

Please amend paragraph **[0049]** as follows:

[0049] Further in accordance with this illustrated embodiment, the instrumented sensor 10 includes a sensing device 30 positioned at the sensor body 12 between the opposing portions of the first wall 14 and second~~ walls 14 and~~ wall 16 for sensing a shear-component stress on the sensor body 12 substantially exclusive of a net normal~~ stress,~~ stress and for outputting a sensor measurement signal, e.g., a strain signal, representative of the shear stress. In preferred embodiments, such as those discussed below, the sensing device 30 is coupled to the sensor body 12 to undergo strain proportional to the stress applied to the sensor body 12. The sensing device 30 outputs strain sensor measurement signals that are proportional to the shear stress and the normal stress applied to the sensor body 12. As measured by the sensing device 30, the strain sensor measurement signals can be manipulated to determine the shear stress applied to the sensor body 12 substantially exclusive of a net normal~~ stress in the sense that~~ stress. Stated differently, the sensing device 30 is capable of measuring stress on the sensor body 12 and apportioning appropriate amounts of the measured stress to the shear-component and to the normal component of the applied stress. This may be done, and in the presently preferred embodiments is done, using, among other things, a sensing device 30 wherein such net normal stress component is canceled out.

Please amend paragraph **[0050]** as follows:

[0050] Although "substantially exclusive" preferably means completely exclusive, it is to be understood that the shear component reading may be influenced slightly by the normal component under certain circumstances. Examples of such circumstances include situations in which non-uniform deformation of the sensor body 12 occurs, such as when loads are applied

~~nonuniformly~~ non-uniformly across the sensor body ~~12 and~~ 12, normal loads ~~that~~ are disproportionately large in comparison to shear load ~~(such as,~~ (for example, a normal load to shear load ratio of ~~100:1) to cause nonuniform deformation of the sensor body 12.~~ 100:1), and the like. Under such circumstances, "substantially exclusive" may mean that the measured shear stress is not completely exclusive of and not totally uninfluenced by the normal stress. However, with the preferred ~~embodiment,~~ embodiment the shear stress component may be measured without undue ~~influence, and preferably~~ influence and, preferably, to the complete ~~exclusion,~~ exclusion of the normal component.

Please amend paragraph **[0051]** as follows:

[0051] The sensing device 30 according to this aspect of the invention comprises first reflective sensor element 32 and second reflective sensor ~~elements 32 and~~ element 34, each of which extends between the opposing portions of the first wall 14 and second ~~walls 14 and~~ wall 16. The first reflective sensor element 32 and second reflective sensor ~~elements 32 and~~ element 34 are coupled to first optical fiber 138 (FIG. 2). It should be understood, however, that the sensor elements 32 and 34 alternatively may be transmissive, with second optical fiber (140 in FIGS. 6 and 7) coupled to opposite ends of the sensor elements 32 and 34 relative to the optical fiber 138. The first sensor element 32 intersects the central x-axis at a first oblique angle α, and the second sensor element 34 intersects the central x-axis at a second oblique angle $-\alpha$, which is equal in magnitude to the first oblique angle α. For example, the oblique angle α may be about 6°. The first and second sensor elements 32 and 34 preferably are symmetrical across the central x-axis and, more preferably, form an "X" shape. The sensor elements 32 and 34 preferably lie in an x-y plane orthogonal to the z-axis.

Please amend paragraph **[0052]** as follows:

[0052] The sensor elements 32 and 34 are positioned and affixed to the sensor body 12 by attaching or fastening them to the appropriate locations using appropriate fastening means. Such fastening means may include bonding the sensors using a suitable bonding agent, ~~for~~

~~example,~~ such as an epoxy or other ~~adhesive, such as~~ adhesive. For example, GA-2, commercially available from ~~Micro-Measurements,~~ Micro-Measurements, Measurement Group, Inc. of Wendell, North Carolina, may be a suitable bonding agent. As shown in FIG. 3, opposite ends of the first sensor element 32 are respectively connected tautly proximate to the first pair of diagonally opposed corners of the block to extend diagonally across the block. Likewise, opposite ends of the second sensor element 34 are respectively connected tautly proximate to the second pair of diagonally opposed corners of the block to extend diagonally across the block and cross the first sensor element 32. It is to be understood that this illustration is not necessarily limiting, in the sense that the ends of each of the sensor elements 32 and 34 may be connected to opposing wall portions not proximate to the corners.

Please amend paragraph **[0053]** as follows:

[0053] Operation of the sensing device according to the preferred embodiments will now be described with reference to FIGS. 4 and 5. In these illustrative embodiments, the first and second sensor elements 32 and 34 are preferably strain gauges, more preferably optical fiber strain gauges. ~~Application~~ Referring to FIG. 4, application of a net positive normal load in the y-direction to the opposing portions of the first wall 14 and second ~~walls 14 and~~ wall 16 will cause the walls 14 and 16 to move toward one another along the y-axis, with the deformed sensor body 12 represented by the dashed lines. As the walls 14 and 16 move toward one another to reduce the spacing therebetween, the first and second sensor elements 32 and 34 undergo compressive strain ~~to output~~ and each sensor element 32, 34 outputs strain sensor measurement signals of equal magnitude representative of the net positive normal component of the deformation stress. On the other hand, application of a net negative (pulling) normal load to the first wall 14 and second ~~walls 14 and~~ wall 16 will increase the y-axis spacing between the walls 14 and 16. Movement of the walls 14 and 16 away from one another imparts a tension strain to the first sensor element 32 and second sensor ~~elements 32 and~~ element 34, ~~which output~~ each sensor element 32, 34 outputting strain sensor measurement signals of equal magnitude representative of the net negative normal component of the deformation stress.

Please amend paragraph **[0054]** as follows:

[0054] Referring now to FIG. 5, application of a shear load to the sensor 10 of the illustrative embodiments will cause the opposing portion of the first wall 14 to move relative to the opposing portion of the second wall 16 along a direction generally parallel to the x-axis. By "generally parallel," it is understood that the shear load may also deform the sensor body 12 to move the opposing portions of the first <u>wall 14</u> and second ~~walls 14 and~~ <u>wall</u> 16 slightly towards each other along the y-axis, as shown in FIG. 5. In FIG. 5, dashed lines represent the displaced sensor body 12. As referred to herein, relative movement ~~can~~ <u>may</u> include displacement of (a) the first wall 14 while the second wall 16 remains fixed (as illustrated in FIG. ~~5),~~ <u>5);</u> (b) the second wall 16 while the first wall 14 remains ~~fixed,~~ <u>fixed;</u> (c) the first wall 14 and the second wall 16 in opposite directions to one ~~another, and/or~~ <u>another; and</u> (d) the first wall 14 and the second wall 16 in the same direction but by different magnitudes from one another.

Please amend paragraph **[0056]** as follows:

[0056] Once the strain sensor measurement signals are obtained from the sensor elements 32 and 34, the shear component of the stress on the sensor 10 can be determined as follows, preferably in the processor 54 or its equivalent. The difference in the outputs of the sensor measurement signals from the sensor elements 32 and 34 yields a strain signal that is proportional to the magnitude of the shear stress in the sensor body 12. In the event that the sensor is subject to a load having a shear component and a normal component, the shear component may be calculated to the exclusion of the normal component. That is, because the proportion of the strain sensor measurement signals attributable to the normal stress acting on the sensor body 12 are virtually identical for each of the sensor elements 32 and 34, subtracting the outputs of the sensor measurement signals will cancel the normal component of the stress, leaving an output signal representing only the shear component. Additionally, any other environmental stimulus that affects both sensor elements 32 and 34 equally, such as thermal

changes, will also be subtracted out in this ~~way,~~ way because the environmental stimulus will generally impart equal compression or tension to both of the sensor elements 32 and 34.

Please amend paragraph **[0058]** as follows:

[0058] The sensor elements 32 and 34 may comprise any sensor or measuring device that can be affixed to the opposing wall portions of the sensor body 12 and can sense or measure strain in the appropriate directions as generally described herein. The specific sensor elements used in a particular application may depend upon a number of factors, ~~for example,~~ such as the size of the interface of the insulation layer 88 and the propellant 84, the material from which the adhesive liner 86 is constructed, the nature and extent of the anticipated forces on the interface and sensor, the durability and requirements of the sensor or sensors with respect to the specific application and operational environment, other equipment with which the device is to be used, etc.

Please amend paragraph **[0059]** as follows:

[0059] Strain gauges are preferred, and optical fiber strain gauges are especially ~~preferred~~ preferred, as the sensor elements 32 and 34. In the exemplary embodiments, each of the sensor elements may comprise an optical fiber strain gauge, such as noncompensated strain gauge Model FOS-N-1000@+1000, commercially available from Fiso Technologies of Quebec, Canada. The structure, ~~operation~~ operation, and use of suitable Fabry-Perot type sensor elements are described in U.S. Patent No. 5,202,939 and U.S. Patent No. 5,392,117, both to ~~Belleville~~ Belleville, et al. Other strain gauges, such as those available from Luna Innovations, may also be used.

Please amend paragraph **[0061]** as follows:

[0061] The sensing device according to one preferred embodiment of the invention comprises the transmissive Fabry-Perot type of optical fiber strain sensor, such as shown in FIGS. 6 and 7, reproduced from U.S. Patent No. 5,392,117. A transmissive Fabry-Perot

interferometer 120 comprises two planar, parallel, reflecting surfaces 122 and 124 spaced apart from one another by some distance ~~d.~~ "d." A Fabry-Perot cavity 126 is defined between the reflecting surfaces 122 and 124. A light signal is fully transmitted if the cavity length ~~d is~~ "d" is an integer number of half wavelength, while the other wavelengths are partly reflected. A light plane wave propagated along the normal of two mirrors 130 and 132 will be partially transmitted, the rest being reflected (losses can be neglected). The transmittance or reflectance function T, defined as the ratio of the transmitted intensity to the incident intensity, of such a Fabry-Perot cavity 126 is given by the following relation:

$$T(\lambda,d) = 1/(1 + F \cdot \sin^2[2\pi n d/\lambda])$$

where:

d is the distance separating the mirrors 130 and 132 (cavity length);

n is the refractive index of the material separating the two mirrors 130 and 132 (for example, for air n=1);

λ is the wavelength of the light signal; and

F (the finesse) is equal to $[4R/(1-R)]^2$, R being the reflectance of the mirrors 130 and 132.

Please amend paragraph **[0062]** as follows:

[0062] For a Fabry-Perot interferometer 120 made up of two mirrors 130 and 132 of a given reflectance R, the finesse F is evidently constant. On the other hand, the cavity length d as well as the wavelength λ of the light signal propagated through the Fabry-Perot interferometer 120 can vary. Consider a Fabry-Perot interferometer 120 with a fixed gap. As calculated with the above equation, the transmittance or reflectance T as a function of wavelength λ takes the form of a ~~sinus~~ sinusoid with a wavelength's increasing period. If the cavity length d varies, the ~~sinus~~ sinusoid will be subjected to a phase shift accompanied by a variation of the period. For a given cavity length d, the transmittance or reflectance T of a

Fabry-Perot interferometer 120 as a function of the wavelength λ is unique. The transmittance or reflectance function T can thus be qualified as a signature of the cavity length d, and this is true for each value of cavity length d. Therefore, the Fabry-Perot cavity length d can be calculated from the transmitted (or reflected) light spectrum.

Please amend paragraph **[0066]** as follows:

[0066] In operation, the luminous flux emitted by the light source 148 (formed, for example, by a quartz-halogen lamp or a broadband LED) is ~~launched~~ transmitted into the first optical fiber 138. The light beam propagated inside the first optical fiber 138 goes through the ~~Fabry Perot~~ Fabry-Perot interferometer 120 to be partially transmitted into the second optical fiber 140 and partially reflected into the first optical fiber 138. By measuring the transmitted light spectrum X(λ) or the reflected light spectrum equal to 1-X(λ), the length d of the Fabry-Perot cavity 126 can be calculated. The calculation can be accomplished by cross-correlating the measured spectrum X(λ) with the theoretical transmittance function T(λ,d) given by the above equation. The ~~cross correlation~~ cross-correlation coefficient is then calculated as a function of the cavity length d with the following relation:

$$C(d)=\frac{1}{M}\cdot\sum_{n=0}^{M-1}X(\lambda_0+n\Delta\lambda)\cdot\frac{1}{1+F\cdot\sin^2\left[\dfrac{2\cdot\pi\cdot n\cdot d}{\lambda_0+n\Delta\lambda}\right]}$$

where the effective cavity length d is given by a maximal cross-correlation coefficient $C(d)_{max}$.

Please amend paragraph **[0069]** as follows:

[0069] This photodetector 160 can be, for example, a linear photodiode array or a CCD array. Therefore, the cross-correlation function C(d) is coded on the pixels of the photodetector 160, each pixel corresponding to a given correlated Fabry-Perot cavity length d. The cavity length d may vary, for instance, from 0 μm to 40 μm. The cavity length d of the Fabry-Perot interferometer 120 is finally given by the position of the pixel reading the maximum

light intensity. The detection of the maximum can then be translated in strain by means of the following relation:

$$\varepsilon = \frac{\Delta L \cdot \tan(\gamma)}{L}$$

where:

ΔL is the distance on the photodetector 160 separating the unstrained coefficient of maximum cross-correlation from the~~ strainedcoefficient; ~~ strained coefficient;

γ is the angle between the flat glass plates 152, 154 of the Fizeau interferometer 150 (approximately 0.03°); and

L is the gauge length of the Fabry-Perot interferometer 120.

Please amend paragraph **[0071]** as follows:

[0071] In accordance with an alternative embodiment, an optical sensing device in reflection is also proposed. Referring to FIGS. 8 and 9, the configuration of such an optical sensing device in reflection comprises an optical coupler 149 optically coupled between the first optical fiber 138, the focusing lens 153 and the light source 148, for coupling the light signal into the optical fiber 138 and for coupling the reflected portion of the light signal collected from the Fabry-Perot cavity 126 and transmitted by the optical fiber 138 into the focusing lens 153. As shown in FIG. 9, the reflective configuration also allows the development of a thermally~~ auto-compensated ~~ auto-compensated optical sensing device. The optical fiber 138 is inserted in one end of the microcapillary 142 and a thin wire 162 made of the same material as the body whose deformation is to be measured (not shown in the Figure) is inserted in the other end of the microcapillary 142. The tip of the wire 162 is coated with~~ an ~~ at least a partially light-absorbing material~~ 164 like ~~ 164, such as Inconel®,~~ exhibiting ~~ which exhibits a reflectance of nearly 30% in order to form a mirror (as shown in FIG. 9), while absorbing the rest of the light signal. The optical fiber 138 cannot move in the bore of the microcapillary 142 since its tip 166 is welded thereto, while the portion 168 of the wire 162 within the bore of the microcapillary 142 can move freely. The gauge length L is entirely in the region of the portion 168 of the wire 162. A

mechanical deformation will produce a variation of the cavity length d in a similar way as described earlier. On the other hand, a thermal expansion of the body (not shown in the Figure) will be compensated by a similar thermal expansion of the portion 168 of the thin wire 162 moving in the opposite direction in the bore. The optical sensing device ~~can~~ may be compensated for different material by changing the material of the thin wire 162 as well.